Cortical Control of Neural Prostheses

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Work Performed During the Reporting Period

In this reporting period, we continued to record spike data from our previously implanted monkeys H and K, and began recording from new implants on monkey M. All three monkeys were trained on the virtual reality (VR) task, and learned to control cursor movement directly from brain signals. We also implemented a protocol to train animals in direct brain control of a robotic arm, and began training monkey M using this protocol. We began work on a neurotrophic electrode design, and sacrificed monkeys H and K to determine the cortical locations of the implants.

Robot training, real-time and direct control

We completed the software for acquiring neuronal data in real time and computing control signals, and incorporated that software into a program which uses an ‘auto-shaping’ paradigm to train the animals in direct control of the robot. In this paradigm, animals are trained to be attentive to some single cue which predicts the availability of a reward. In our case, we wanted the animals maximally attentive to the robot, and so our cue is movement of the robot. In the initial stages of the training, the robot is used to retrieve a piece of fruit and deliver that fruit to the animal. The movements by the robot are very slow, taking up to 15 seconds to actually deliver the fruit. We allowed 30-60 minutes of training daily using this paradigm for one week, during which the animals get used to the movement of the robot, and learn to associate movement of the robot with the delivery of a reward.

Following this initial period, we provided the animal with the ability to increase the speed of delivery by driving the robotic arm with direct control from the brain. Our paradigm has been to provide a rapid delivery of the fruit if the animal moves the robot arm within a threshold distance from the target zone. We have worked with two animals on this paradigm. To this point, we have seen a steady decrease in the amount of time taken to deliver the fruit, indicating that the animals are exhibiting some modest control over the robot arm. However, we have not seen evidence thus far that either animal has made the stimulus-response association between mental (brain) activity and the motion of the robot.

VR training, direct control

We have trained two animals in direct brain control of the cursor in the VR task (see previous report for a full description of the task). The animals begin the work day by performing 80 to 120 arm movements to eight targets in the 3d center->out task. We acquire spike data during this part of the task, and use the relations between arm movement and neuronal firing in each of the neurons to create a mapping between ensemble activity and cursor movement based on the population vector algorithm. For the remainder of the day, the animals alternate, performing 8 arm-controlled center->out movements, followed by 8 brain-controlled center->out movements in which the cursor motion is determined directly from brain activity. In the arm-controlled mode, the animal receives a single reward for placing the cursor into a target. In the brain-controlled mode, the animal receives one reward per second for each second that the cursor is maintained within a target, for up to five seconds.

Two measures taken during the brain-control mode have shown daily improvements as the animals perform this task. The first is the mean angle between the direction of cursor movement and the direction from the cursor to the target. That angle has steadily decreased in both animals. The second is the amount of time the cursor spends within the target. That time has steadily increased in both animals.

Neurotrophic electrode

We finalized a design for our first attempts at a neurotrophic electrode. Each electrode in a recording array will consist of a microwire electrode carried inside a polyimide sheath. The polyimide sheath will be filled with a fibrinogen gel that has various amounts of a recombinant NGF bound into it. The fibrinogen is labile under *in vivo* conditions, so that a steady delivery of NGF will occur over a period of days or weeks as the exposed fibrinogen is degraded by biological processes.

Work anticipated for the Next Reporting Period

We will continue with the auto-shaping paradigm to generate the stimulus-response association for control of the robotic arm. We will also be considering alternative methods of training the animals in direct control of the robot.

In the VR task, we will turn our attention to more detailed questions about the animals' capabilities in direct control of cursor movement. To date, our training has focused on the case where the animals are free to move their arms. This produces good control of the cursor in certain cases, but we would like to see if the animals can also control the movement of the cursor with their arms restrained. We have also been relying on the properties of the entire recorded ensemble to create our mappings between cortical activity and cursor movement. We will be extending the work by assessing the animals' ability to control the cursor when the cursor movement is dependent on the activity of single neurons.

We expect to have the neurotrophic gel for the electrodes well-enough worked out to build a few implantable arrays, which we will install in a rat model to make some initial assessments of our design.

We will also be preparing for histological analyses of the implants in monkeys H and K, both to see the locations of the implanted arrays, and to see if there is any obvious pathological clues that can help us understand the variable reliability of the implants to date.

Finally, we plan to implant several recording arrays in the next reporting period in order to have good data to use as we continue to refine our training paradigms.